Repair of concrete pavements by thin concrete overlays

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Abstract

In consideration of continuously increasing traffic and high exposure to freeze-thaw and deicing salt, maintenance and repair works of concrete pavements become of crucial importance. An alternative to the conventional replacement of the entire concrete structure is the application of thin-layered new concrete. For this procedure, only the upper part of the existing pavement, which is impaired, is removed and will be replaced by a thin layer of new concrete. The crucial factor here is the bonding behavior between the lower layer (old concrete) and the thin layer of new concrete. The objective of this research was to investigate the influence of cyclic loading and freeze-thaw-cycles with deicing salts on the bonding properties of such concrete layers. Herein, a number of parameters were varied, including the moisture condition of the old concrete, the application of adhesion primer, the consistency of new concrete etc. These studies are of interest for researchers as well as for practitioners.

Introduction

Concrete pavements are exposed to a number of stresses during their service life, mostly resulting from traffic and climate conditions. In consideration of continuously increasing traffic, the durability requirements of concrete pavements become more and more significant. In addition, these pavements have to fulfill further specifications regarding surface properties such as sufficient texture and adequate noise reduction . Thus, the maintenance and repair of concrete pavements become of crucial importance for a long service life. Herein, the main aim is to find the most economically efficient construction method through minimizing life cycle costs without affecting the functionality and quality of concrete pavements.

Usually, maintenance of concrete pavements is conducted through the replacement of the entire damaged structure. An alternative method is the renewal of only the upper part of the existing pavement if the damages are concentrated only in this upper lift. In this case the milled old concrete provides the base course layer for the new concrete.

In case of the so-called and often used “Whitetopping” a thin concrete layer, usually a fiber-reinforced high performance concrete with low-shrinkage characteristics is applied to an existing asphalt pavement. For conventional Whitetopping concrete, paving thicknesses range between 200 and 260 mm. For Thin-Whitetopping (TWT) an overlay of more than 100 mm and less than 200 mm is most commonly used. The thickness of Ultra-Thin Whitetopping (UTW) usually doesn´t exceed 100 mm (Eid 2012).

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The maintenance of concrete pavements by applying only a thin layer of new concrete on the old pavement is a relatively new field of work. In this context, the upper part of the existing pavement, which is impaired, is removed and will be replaced by a thin layer of new concrete. The crucial factor is the durable bonding between the lower layers (old concrete) and the thin layer of new concrete, which largely depends on the mechanical and rheological properties of both concretes as well as on the surface condition (moisture, roughness) and joints.

First pilot projects have been carried out in Austria on the motorway A14 Rheintal and A1 between Salzburg Center and Salzburg West (Spalt 2012). The concrete pavement on the A 14 had an insufficient grip on the surface while in the concrete pavement on the A1 edges had been chipped. Therefore, both routes needed maintenance, which was realized in 2009 and 2010 respectively. Up to now these two applications in situ show no significant damages.

Laboratory investigations

Parameter variation and production of large concrete beams. Besides these two test projects the application of thin concrete layers on old concrete pavements has been studied within the scope of an extensive research program. For this purpose characteristic concrete mixes complying with the German guideline "TL Beton-StB 07", were used. The old concrete corresponded to a characteristic base-lift-concrete with a maximum aggregate size of 22 mm, the new one to an exposed-aggregate-concrete with a maximum grain size of 8 mm.

In order to investigate the bonding behavior, large concrete beams with dimensions of 180 x 50 x 27 cm^3, consisting of a lower layer (old concrete, thickness approx. 20 cm) and a thin top layer (new concrete, thickness approx. 7 cm) were produced. Before the new concrete was applied, the surface of the concrete beams was roughened using high pressure water jets (2000 bar) at a minimum age of 28 days.

The compressive strength of the "old" concrete generally amounted to approximately 60 MPa, in two cases it amounted to about 80 MPa. Furthermore, the moisture condition of the bond area (horizontal structural joint) was varied by producing a dry and alternatingly a moist surface before applying the new concrete.

The concrete design of the new concrete was varied by adding shrinkage reducing agents to a conventional concrete design with exposed aggregate surface. In addition, the consistency was varied by appropriate dosage of superplasticizer.

In case of some large concrete beams, polymer modified adhesion primer was used. The new concretes were casted with a stiff consistency (C1/C2) as well as in soft consistency (F4 according EN 206).The exposure time of the adhesive primer prior to application of the new concrete was ranged between 20 and 30 minutes. In one case, an exposure time of 2 hours was chosen. The application of the adhesion primer was generally conducted at an ambient temperature of approximately 20 °C. In one variation, the ambient temperature was about 30 °C.

Cyclic loadings and freeze thaw exposure. At an age of 56 days (after pouring the "new" concrete) the large concrete beams were loaded cyclically in 4-point-flexural-tests with up to 1 Mio. load cycles (Figures 1 and 2). In these tests a stress level of $\sigma_{max}/f_{ct,fl} = 0.4$ ($f_{ct,fl}$ = 4.5 MPa) was set. The load range (σ_{max} - σ_{min}) was defined by 1.0 MPa.

Figure 1. Test setup for simultaneous testing of six beams in a 4-point-flexural-test

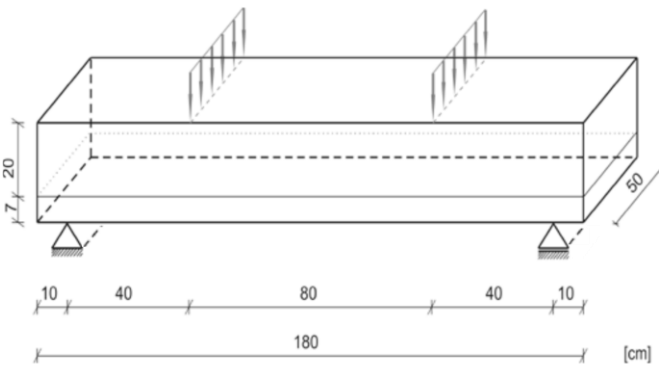
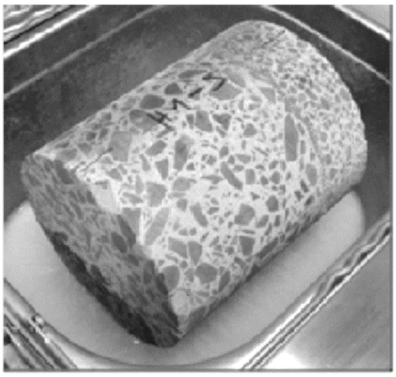


Figure 2. Test setup for cyclic loading of concrete beams (180 x 50 x 27 cm³)

Subsequent to the cyclic loading, cores with diameters of d = 100 mm and d = 150 mm resp. were taken from the unloaded reference area above the beams support ("Reference") as well as from the maximum loaded section ("Cyclic loading") in the middle of the beams. Some of the latter cores (taken from the maximum loaded section were additionally exposed to freeze-thaw-attack based on a modified CDF-test (Setzer 2006) before investigating the bond. This test includes a capillary suction period of 7 days followed by 28 freeze-thaw-cycles according to the temperature cycle in displayed Figure 3. These specimens are further nominated as "Cyclic loading+ FT-attack".



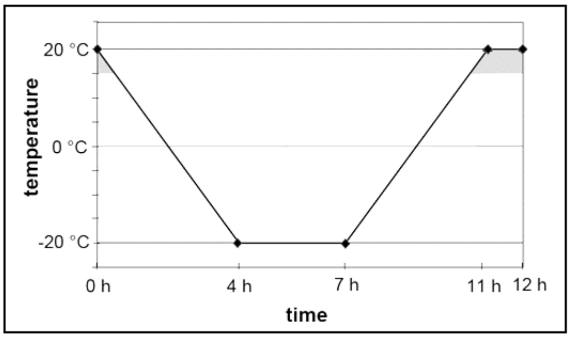
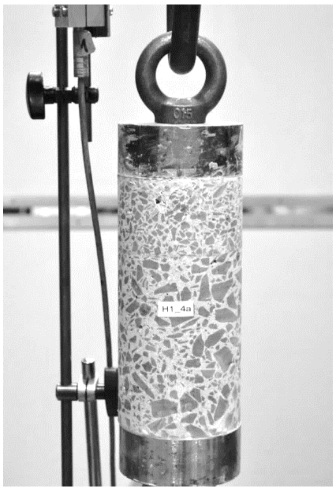


Figure 3. left: freeze-thaw-attack on drilling core; right: temperature cycle for one freeze-thaw cycle

Bonding properties of old and new concrete. The adhesive strength and adhesive shear strength between old and new concrete were determined on the recovered drilling cores. The adhesive strength was determined according to the European standard “EN 14488-4:2008” on cylinders with d = 100 mm, l = 200 mm gained from the cores. For this purpose, steel intender with a thickness of about 40 mm were applied to the cross cut ends. The tests were performed in a servo-hydraulic test machine (capacity 250 kN). The tensile load was yield by eyebolts and hooks into the intender (Figure 4, left). The strain rate amounted to about 0.4 % mm/min.



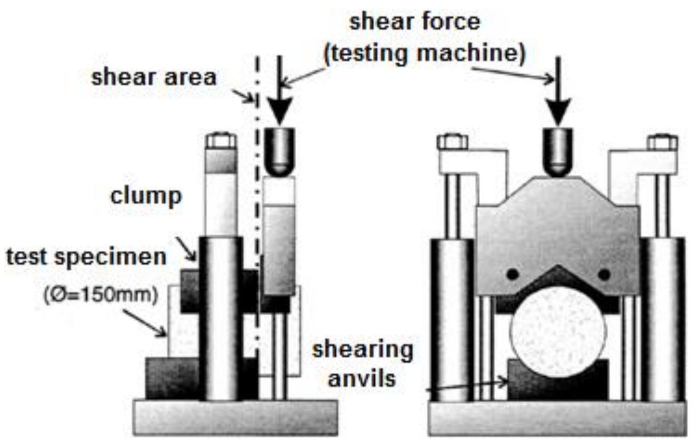


Figure 4. left: Investigation on the adhesive strength of drilling cores consisting of old (thickness approx. 140 mm) and new concrete (thickness approx. 60 mm); right: Test setup for shear test

The adhesive shear strength was determined with a device in correspondence with the German guideline “TP Asphalt-StB Teil 80” on cylindrical specimens (d = 150 mm, l = 180 mm). In this test setup, a shear load was applied directly into the bond area between the old and the new concrete. For this purpose the “old” concrete part has been fixed in the test frame and the load was applied perpendicular to the core as close as possible to the bond area (Figure 4, right). The deformation rate amounted to about 0.6 mm/min.

Results

Within the test series varying the moisture conditions in the bonding area at application of the new concrete it was found that the adhesive strengths and adhesive shear strengths are slightly larger when the bond area was dry (Figure 5). When using an adhesion primer this effect could not be proved in the same manner (Figure 6).

According to the German guideline "ZTV-ING" a sufficient bond between new and old concrete can be assumed if the surface tensile strength exceeds 1.5 MPa. The adhesive strengths gained in most of these tests (mostly above 2.0 MPa) were significantly higher than this mentioned value. In nearly all specimens the fracture occurred within the "old" concrete. Thus it can be assumed that between old and new concrete an adequate high bond can be obtained under these conditions.

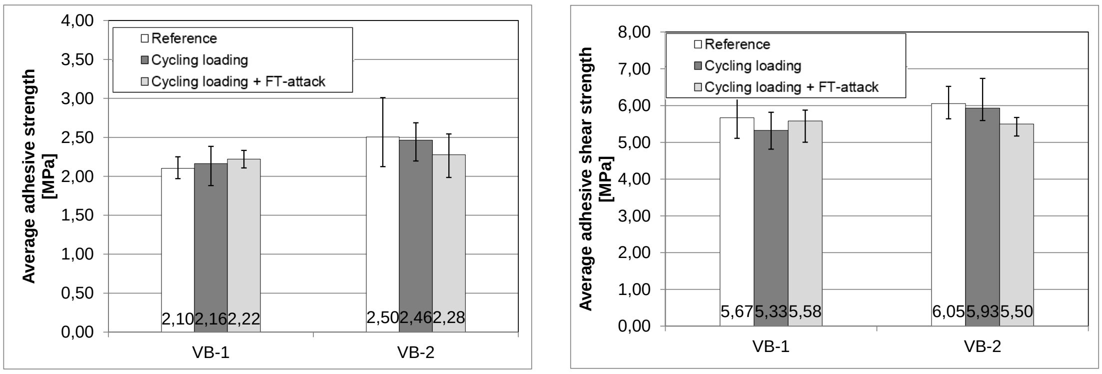


Figure 5. Average adhesive strength (left) and adhesive shear strength (right) of VB-1 and VB-2 (without adhesion primer, without SRA, consistency F4); VB-1: moist condition and VB-2: dry condition (of the bond area)

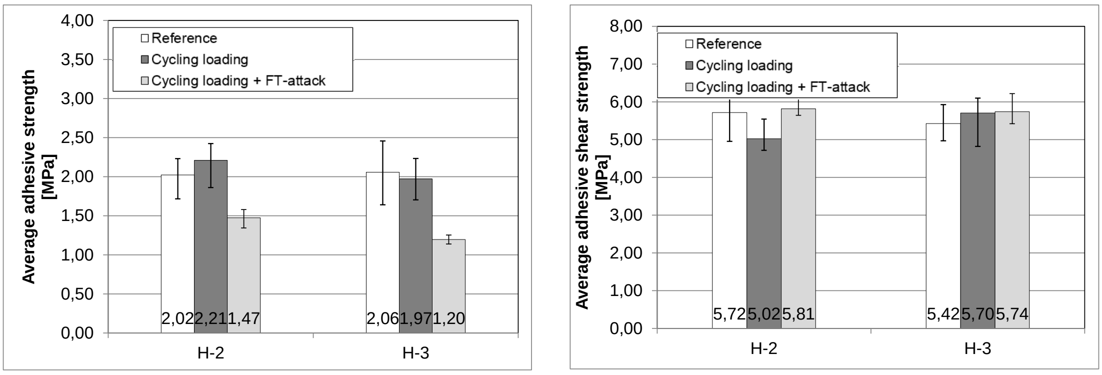


Figure 6. Average adhesive strength (left) and adhesive shear strength (right) of H-2 and H-3 (with adhesion primer, with SRA, consistency C1/C2); H-2: moist condition and H-3: dry condition (of the bond area)

In most cases, there was no significant difference between the different "exposures" (Reference, Cyclic loading, FT-attack). For some of the specimens though, whose new concrete contained shrinkage reducing agents, the fracture after freeze/thaw-attack occurred within the new concrete. The adhesive strengths of these specimens were significantly lower in comparison with reference samples (up to 42 %). Although the air content in fresh concrete matched the requirements. The requirements regarding the air-void-parameters were not met in the hardened concrete. Thus an negative impact between the air-entraining agent and the SRA has to be considered. With respect to the bonding behavior, the adhesive strengths after cyclic loading was about as high as at the reference specimens when SRA was used in the new concrete. The adhesive shear strengths then again were slightly larger (Figure 7).

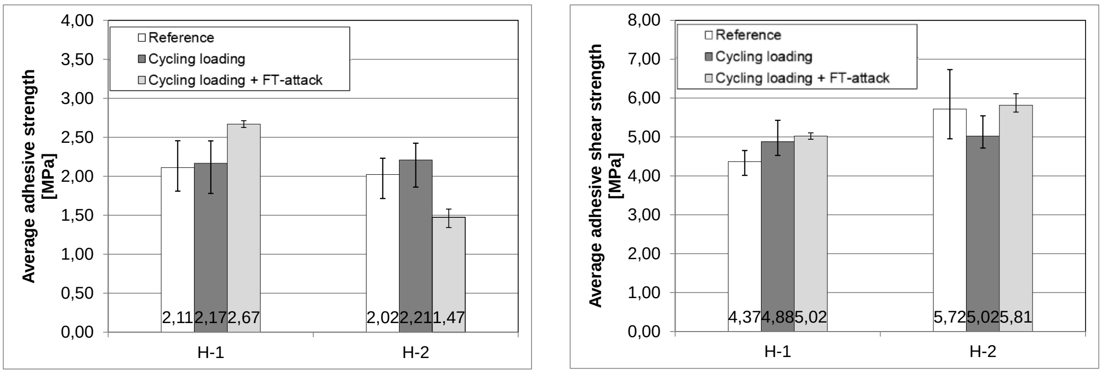
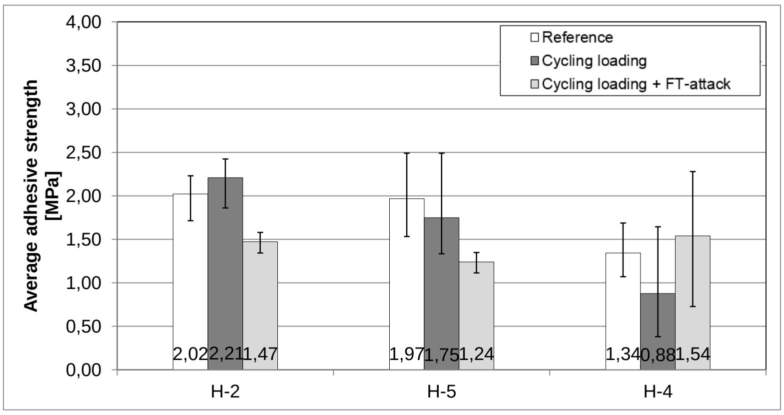


Figure 7. Average adhesive strength (left) and adhesive shear strength (right) of H-1 and H-2 (moist condition, with adhesion primer, consistency C1/C2); H-1: new concrete without SRA and H-2: new concrete with SRA

When the new concrete was poured with stiff consistency also with an adhesion primer applied before significant improvements in the bond could not be proved. However, when there was a longer period between the application of the adhesion primer and the casting of the new concrete as well as the ambient temperature was higher (30 °C instead of 20 °C) negative effects on the bond between the two layers was determined (Figure 8).



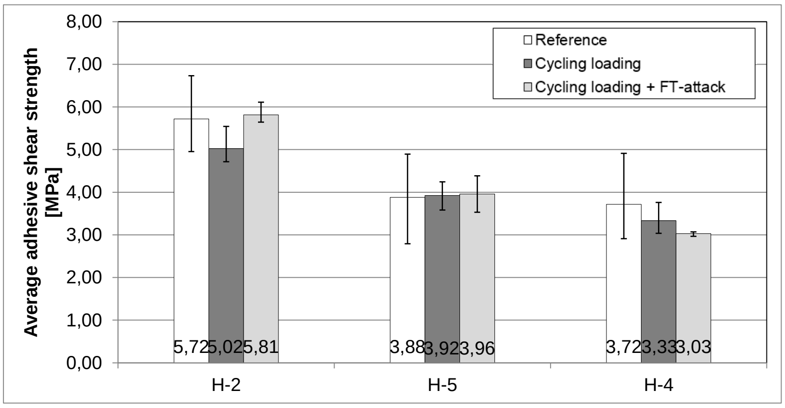


Figure 8. Average adhesive strength (top) and adhesive shear strength (bottom) of H-2, H-5 and H-4 (moist condition, with adhesion primer, with SRA, consistency: stiff - class C1/C2); H-2: waiting period after application of the primer about 0.5 hours; H-5: waiting period about 2 hours; H-4: ambient temperature 30 °C

In view to the compressive strength of the old concrete, it was found that with a soft consistency (class F4) and a higher compressive strength also the bond strengths was increased. (Figure 9). However, when the consistency was nearly flowable (class F 5) the adhesive strength was reduced significantly. Thus it can be assumed, that at higher strength of the old concrete with a comparably dense microstructure a very soft / flowable new concrete forms a “weak zone” in the bonding area due to a slightly formed water film. Contrary, old concrete with lower strength is able to absorb some water from the new concrete and thus an improved bond can be obtained (Figure 10).

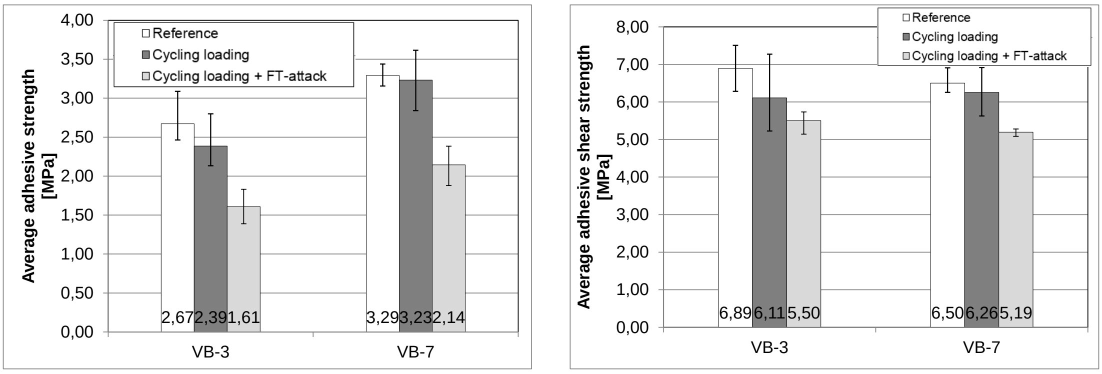


Figure 9. Average adhesive strength (left) and adhesive shear strength (right) of VB-3 and VB-7 (moist condition, without adhesion primer, with SRA, consistency: soft - class F4); VB-3: compressive strength approx. 62 MPa and VB-7: compressive strength approx. 86 MPa (of old concrete)

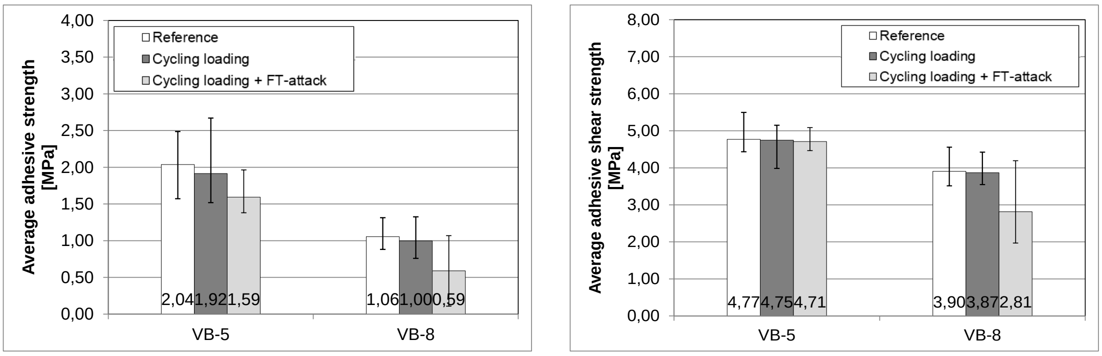


Figure 10. Average adhesive strength (left) and adhesive shear strength (right) of VB-5 and VB-8 (moist condition, without adhesion primer, with SRA, consistency: flowable - F5); VB-5: compressive strength approx. 67 MPa and VB-8: compressive strength approx. 84 MPa (of old concrete)

Conclusions

In numerous lab-tests the influences of numerous relevant parameters on the bond between an old concrete sub-base and a thin layer of new concrete were studied. The bonding properties between the two concrete layers were determined after various pre-loadings, particularly the adhesive strength as well as the adhesive shear strength.

It could be proved that the moisture condition of “old” pavement concretes at the time of applying the new concrete as well as the use of an adhesion primer are only of minor importance. A new concrete with soft consistency effected the bond behavior positively, so that also without an adhesion primer the targeted minimum bond strength of 1.5 MPa was exceeded significantly. In specimens where the new concrete contained shrinkage reducing agents (SRA), an impair in bond was observed which mainly can be attributed to an incompatibility with the air entraining agent. Thus, the use of SRA in concrete for pavements needs further investigation to clarify the necessary measures for a robust concrete.

References

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